TWO TEMPORAL PARAMETERS OF THE MAINTENANCE OF AVOIDANCE BEHAVIOR BY THE WHITE RAT[1]

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A formulation of avoidance behavior offered by Schoenfeld (3) emphasizes three aspects of all successful avoidance conditioning procedures: (*a*) The avoidance response (R_{av}) is never paired with the noxious stimulus. (*b*) All nonavoidance behavior is capable of producing the noxious stimulus and acquiring aversive properties. (*c*) R_{av} is strengthened when it terminates exteroceptive stimulation and/or nonavoidance behavior which has become aversive through pairings with the noxious stimulus.

The critical importance of escape from nonavoidance behavior has been brought out in a series of studies which did not utilize a warning signal (1, 5, 6). In these experiments, however, R_{av}, in addition to preventing the onset of the noxious stimulus, terminated the latter when it did appear. Even this source of strength was eliminated in an experiment by the writer in which no warning signal was presented, and the noxious-stimulus duration was independent of R_{av} (4). The procedure consisted of the presentation of a brief shock at selected intervals, with the provision that any occurrence of R_{av} delayed the shock. No other contingencies between R_{av} and exteroceptive stimulation were involved. The only event which could have signalized the onset of shock was the occurrence of nonavoidance behavior which had previously been paired with shock, and the termination of this behavior presumably provided the reinforcement for R_{av}.

It was noted that continued conditioning with the above procedure produced an avoidance rate which remained stable from day to day. The present experiment was designed to investigate the effects of two temporal variables upon the maintenance of this steady rate.

The independent variables are the durations of the response-shock (R–S) and shock-shock (S–S) intervals. The R–S interval is the period by which each R_{av} delays the shock, or the minimum interval after which a shock can occur following R_{av}. The S–S interval is the time lapse between two consecutive shocks if no R_{av} occurs between them.

On the basis of the three procedural features noted above, certain predictions concerning the effects of these temporal variables are possible. These will be discussed in conjunction with the results presented below.

METHOD

Apparatus

Bar pressing was selected as the avoidance response. The bar, 3⅞ in. long and 5/16 in. in diameter, protruded ½ in. into the cage. Approximately 9 gm. of force was required to depress the bar, while a depression of ⅜ in. closed a microswitch which activated the recording and shock-delay circuits. The experimental boxes, made of galvanized iron, had a floor area of 10½ by 8 in. and an inside height of 11¼ in. The floor was a grid composed of ¼-in. stainless steel rods ⅞ in. apart, measured from center to center, a sufficient distance to prevent animal droppings from shorting out the shock. The bar was 4¼ in. above the grid. To minimize bar presses resulting from jumping responses, a false ceiling of transparent plastic sloped from the top rear of the cage to a position 2 in. above the bar. Both the bar and the walls of the cage were included in the shock circuit. Grid and bar were sandpapered before each experimental session.

The shock was applied by energizing the 110-v. primary of an 880-v. step-up transformer, and was delivered through a 440,000-ohm resistance in series with the grid. A "grid-confuser," which rapidly alternated the side of the circuit supplying each grid rod, ensured that the animals would receive a pulsating shock regardless of which rods they were standing on. The control apparatus, a system of relays, timers, and associated circuit elements located in the experimental room, did not provide cues for the occurrence of the shock because noises did not occur in any consistent temporal relation to the shock. Timers were calibrated and preset before each experimental session. Illumination was constant during and between experimental sessions.

[1] This paper is a portion of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Faculty of Pure Science, Columbia University. The writer is indebted to Professors William N. Schoenfeld and Fred S. Keller for their constructive suggestions during the course of this research.

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Subjects

Subjects were three male Wistar rats. At the start of experimentation, *S*s 40 and 41 were 275 days old, and *S* 46 was 230 days. At the end of experimentation Rat 40 was 553 days, Rat 41 was 607 days, and Rat 46 was 448 days old. The majority of experimental sessions, each 3 hr. long, occurred on successive days, the animals being run at the same time every day, one animal at a time. Each rat was given several preliminary sessions at different shock schedules to ensure that the rate of avoidance responding was stable before recording experimental data.

Procedure

The temporal relations involved were the following: shocks were presented at regular intervals as long as no bar-pressing response was emitted. Any occurrence of a bar press, however, delayed the appearance of the next shock for a specified interval after the response. The time between successive shocks if no bar press occurred is the shock-shock (S–S) interval; the interval by which each response delayed the shock is the response-shock (R–S) interval. For example, on a shock schedule of S–S = 15, R–S = 30 sec., shocks occurred every 15 sec. unless a bar-pressing response was emitted. Every bar press delayed the shock for a period of 30 sec. from the response. If a bar press occurred, e.g., 10 sec. after one shock, the next shock would appear 30 sec. after that response, the interval between the two shocks being 40 sec. Additional responses would delay the second shock still further. In this example a minimum interval of 30 sec. is assured between bar depression and shock. Only the initial bar depression

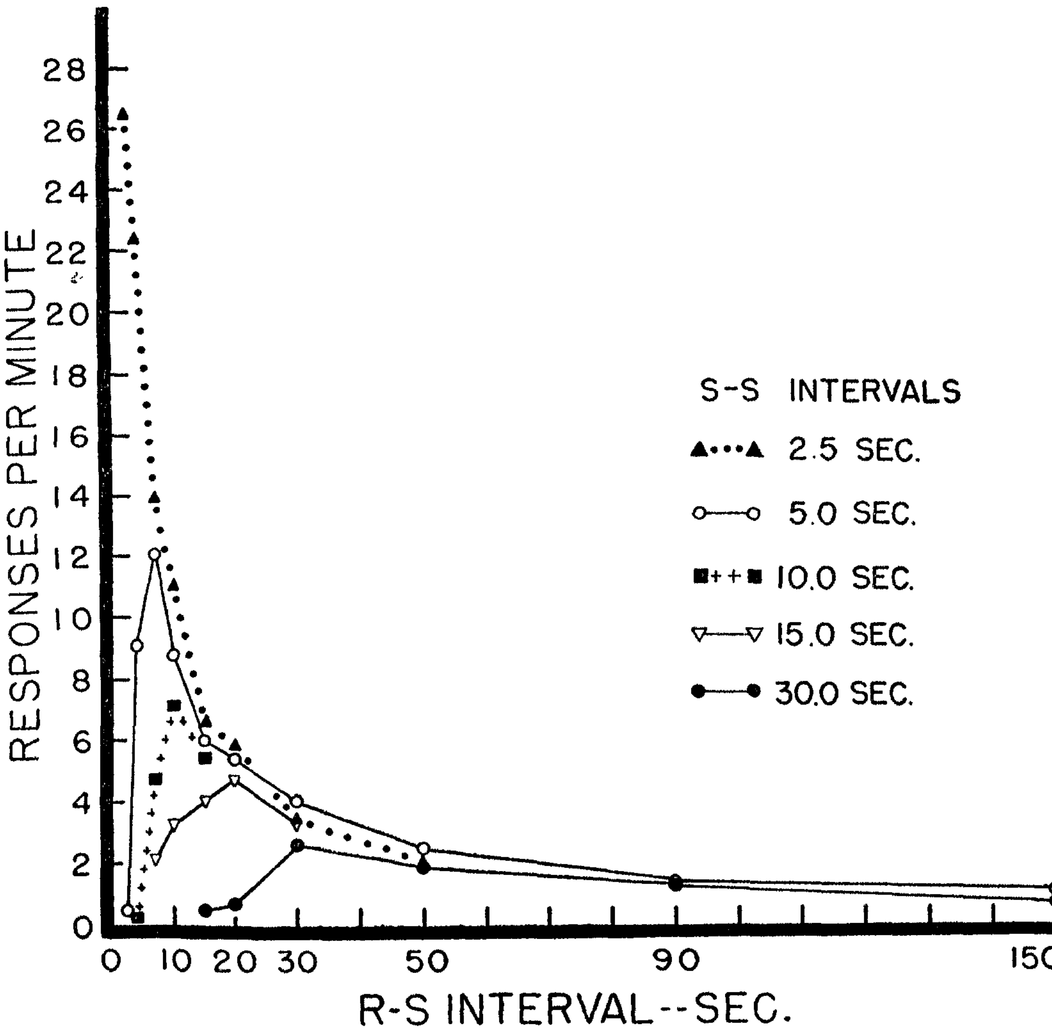

FIG. 1*A*. Rate of avoidance responding by Rat 46, plotted against the response-shock interval, with the shock-shock interval as a parameter

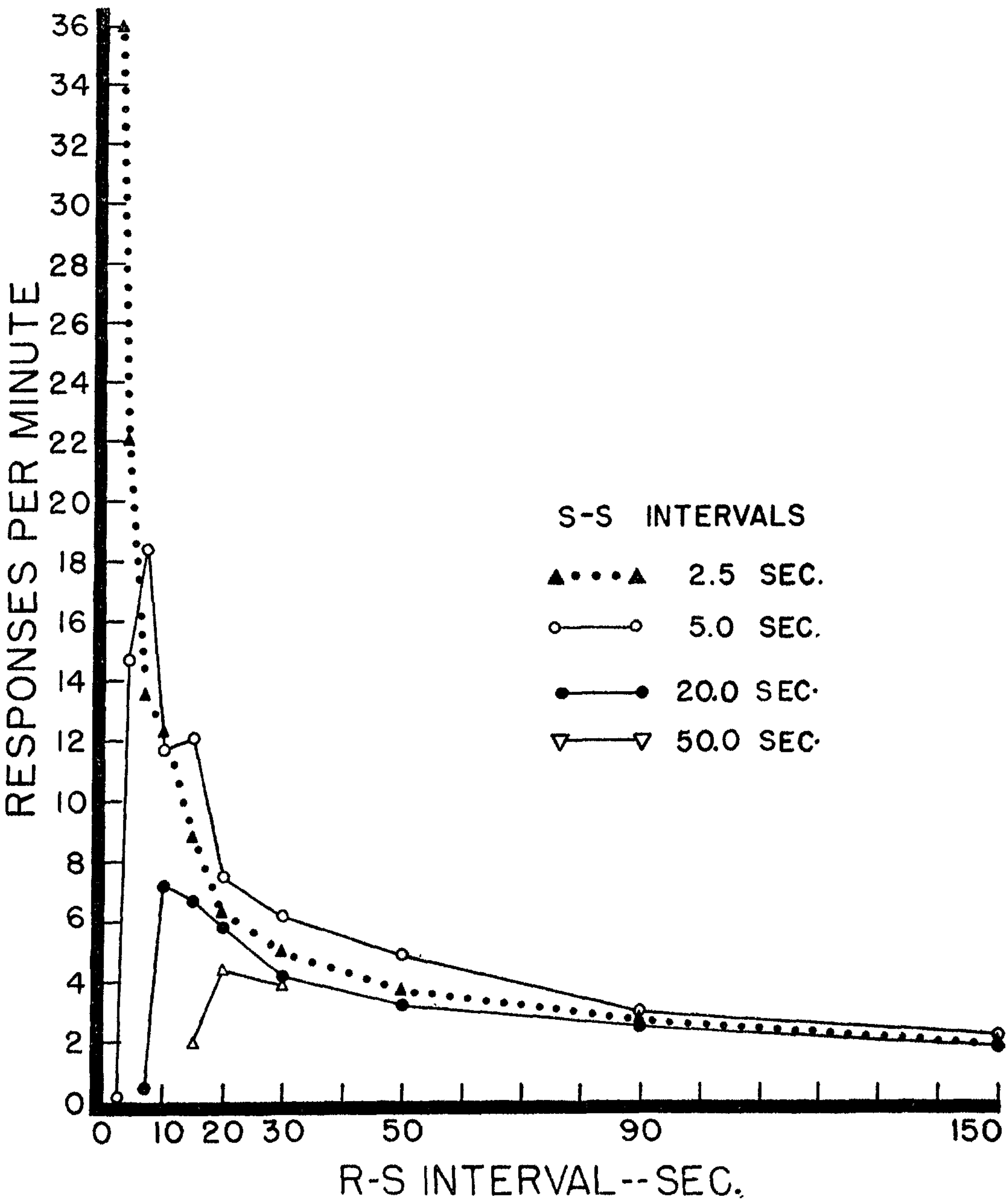

FIG. 1*B*. Rate of avoidance responding by Rat 41, plotted against the response-shock interval, with the shock-shock interval as a parameter

delayed the shock; holding the bar down did not affect the interval. Shocks were of a fixed 0.2-sec. duration.

Experimental Design

Response rates were obtained for each animal at various combinations of S–S and R–S intervals. When enough experimental points were secured to indicate the shape of one rate vs. R–S-interval function, with the S–S interval constant, the S–S interval was changed and another rate vs. R–S-interval function obtained. A family of such curves was generated by each animal. The points on each function were secured in different sequence, and the S–S intervals were presented to each

animal in a different order.[3] Of the 138 experimental points comprising the curves, 5 were determined a second time, the second value being utilized in the accompanying data. These few points were redetermined because they were originally so far out of line that their validity was extremely doubtful. In all cases the second value was consistent with the remaining points on the curves.

Each animal was run on a given schedule until a steady rate was maintained. The criterion of steadiness required, before changing from one schedule to another, was a difference in rate not greater than 0.1 responses per minute between any two out of three consecutive sessions. Only the third hour of each 3-hr. experimental period was used in measuring these rates. Response rates presented below are those prevailing during each criterion period.

One reason for discarding the responses of the first 2 hr. was that the length of the "warm-up" period usually observed at the start of each session appeared to be a function of the current schedule. Inclusion of this period would have influenced the average rate differentially at each shock schedule. Second, in changing from a schedule at which a low rate prevailed to one which gave a high rate, and vice versa, the rate adjustment was often complete by the third hour of the new schedule. By utilizing only the responses in the third hour, it became possible to meet the criterion of a steady rate within the first two sessions of a given schedule. The time saving accomplished by this procedure was considerable.

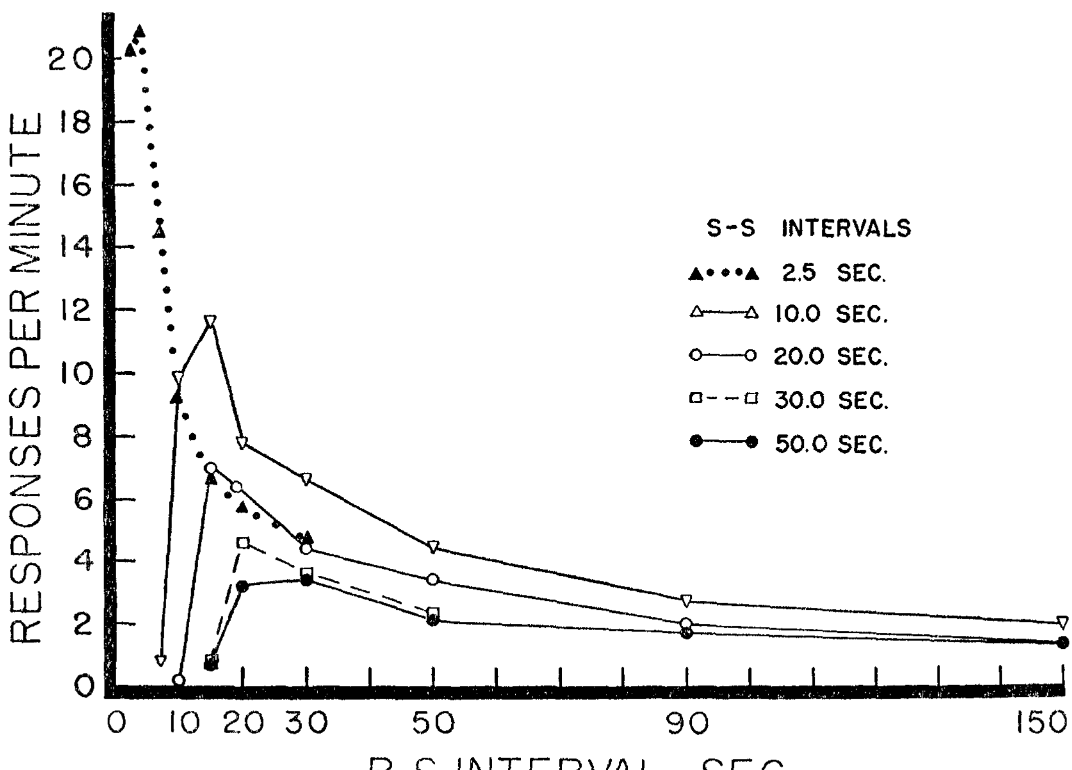

FIG. 1C. Rate of avoidance responding by Rat 40, plotted against the response-shock interval, with the shock-shock interval as a parameter

RESULTS

Data relating avoidance rate and R–S interval are plotted in Figures 1*A*, 1*B*, and 1*C*. Only enough of the tabulated rates have been plotted to illustrate the general trends.[4] That each *S* yielded replicative functions with respect to the shapes of the curves can be seen by inspection and is more precisely demonstrated below. Neither the sequences employed for presenting the intervals nor the increasing

[3] The order of presentation of the shock schedules is contained in Table 1, which has been deposited with the American Documentation Institute. To obtain this table and Table 2, order Document 4017 from ADI Auxiliary Publications Project, Photoduplication Service, ℅ Library of Congress, Washington 25, D. C., remitting $1.25 for microfilm or $1.25 for photocopies.

[4] Tables of the complete data may be obtained from the author.

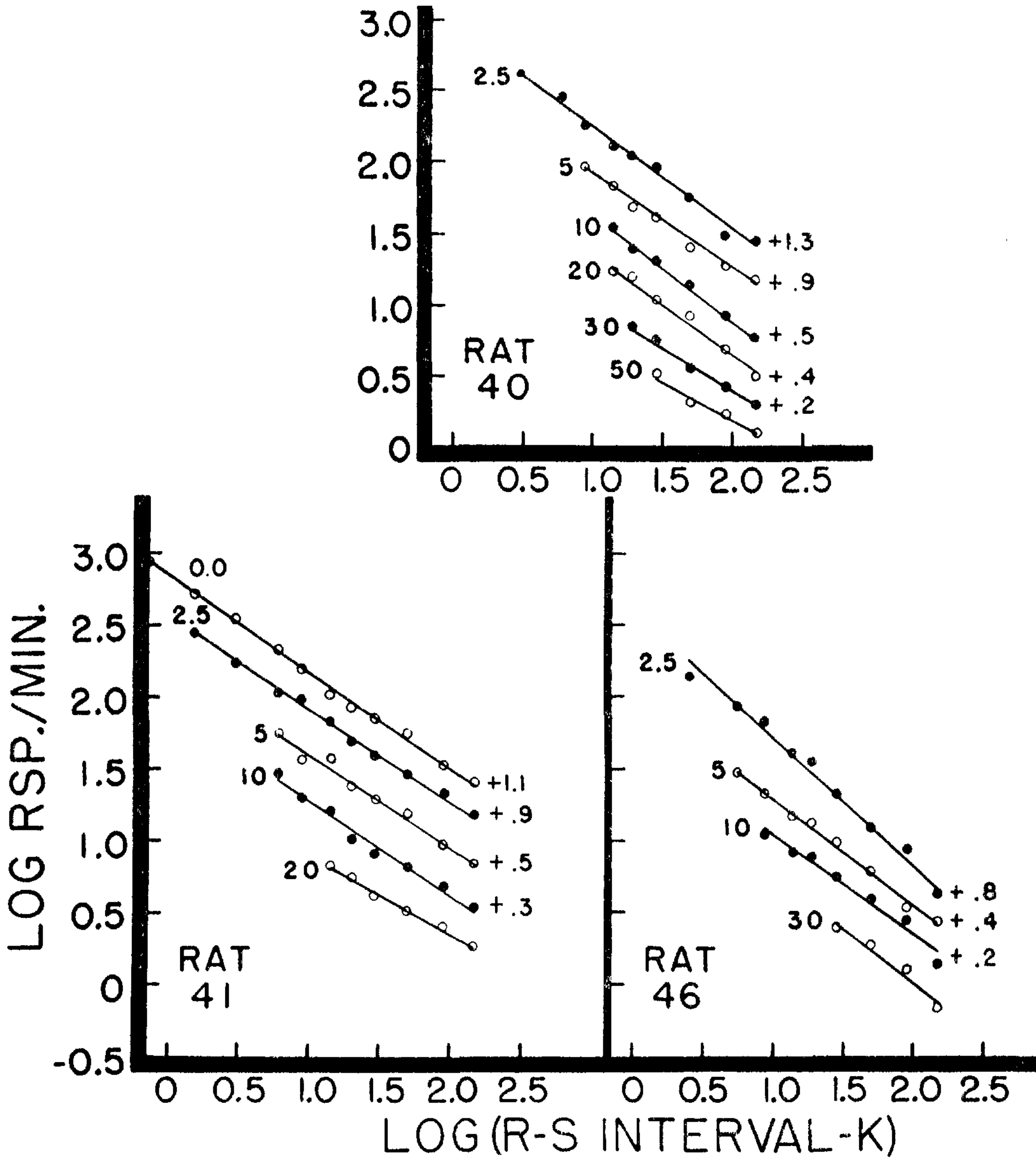

FIG. 2. Log avoidance rate plotted against log response-shock interval for those points at the right of the maxima in Fig. 1. Numbers at the left of each function identify shock-shock intervals, while those to the right indicate the displacement, in log units, of each curve on the ordinate.

ages of the animals affected the orderliness of the data.

As the R–S interval decreases, the avoidance rate increases to a maximum and then falls off rapidly almost to zero at shorter intervals. (Three curves do not show a maximum because the animals did not survive exposure to shorter R–S intervals.) Along with the rates, the number of shocks received in the criterion periods increases as the R–S intervals become shorter.[5] There is no maximum, however, in this function.

In Figure 2 the gradients to the right of the maxima in Figure 1 have been fitted by the

[5] Data relating to number of shocks received in the 1-hr. criterion period for each rat and each schedule are contained in Table 2, deposited with ADI. See footnote 3.

method of averages to a logarithmic transformation of the hyperbolic equation,

$$R = a(t - k)^{-b},$$

where R is the rate of avoidance responding, t is the R–S interval, and a, b, and k are constants. The constant k is specific to the organism and independent of the temporal parameters. To obtain separation, the curves have been displaced upward on the ordinate by the indicated number of log units. These curves indicate clearly that the S–S interval plays no part in determining the *shape* of the rate vs. R–S function to the right of the maximum. It may be noted that the zero S–S-interval curve (Rat 41) is of the same shape

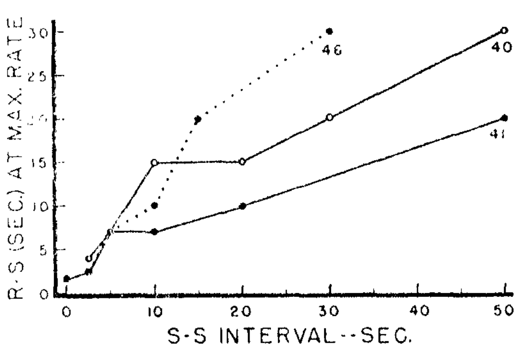

FIG. 3. Response-shock interval at which the maximum rate occurs in each rate vs. response-shock interval function for the three animals

as the others, even though the zero interval, equivalent to continuous shock, actually provides an escape situation. Bar pressing provides for both avoidance of and escape from the noxious stimulus, but the curve is of the same form as the curves which appear to involve only avoidance.

Unfortunately, not enough curves could be obtained to provide an unambiguous picture of the relation between the S–S interval and the constants a and b, though it does appear probable that b remains relatively constant over a wide range of S–S values.

The influence of the S–S interval upon the functions of Figure 1 shows up most clearly at and to the left of the maxima. Although the latter portions of the curves contain too few points to permit a satisfactory mathematical description, certain consistent characteristics may be noted. In each curve there appears to be an R–S interval below which avoidance responding is completely eliminated. Between this interval and the maximum there is a rapid increase in rate. The range of R–S intervals over which the avoidance response is eliminated increases with the S–S interval. Also, as the S–S interval increases, the rise in rate up to the maximum is more gradual. For example, consider the 10-sec. S–S curve of Figure 1C. R_{av} is completely eliminated at intervals of zero to approximately 7 sec. The rise to the maximum occupies the intervals

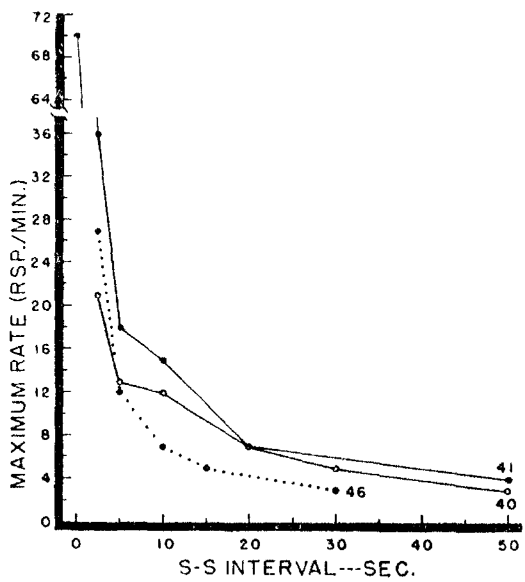

FIG. 4. Maximum rate on each rate vs. response-shock interval function for the three animals, plotted against the shock-shock interval

from 7 to 15 sec., a range of 8 sec. In the 50-sec. S–S curve, however, the response is eliminated at intervals of zero to approximately 15 sec., while the rise to the maximum occupies the intervals from 15 to 30 sec., a range of 15 sec.

Figure 3 reveals a relation between the S–S interval and the R–S interval at which the maximum occurs in each rate vs. R–S function. Individual curves show the same general trends, the irregularities probably resulting from the lack of precision in determining the maximum rates, which are specifiable only within a range of R–S intervals. There is little doubt, however, that the function is a rising one.

The maximum rate on each function is

plotted against the S–S interval in Figure 4. Again, despite local irregularities, the functions appear to be of the same type for each animal, the maximum rate decreasing as the S–S interval increases.

Curves relating rate of avoidance responding and S–S interval, with the R–S interval as a parameter, reflect complex interactions among several processes, but are highly consistent among the three animals. Figure 5 will serve as a model for describing the data of all three animals. Again, some points have been omitted in order to make the graph more readable.

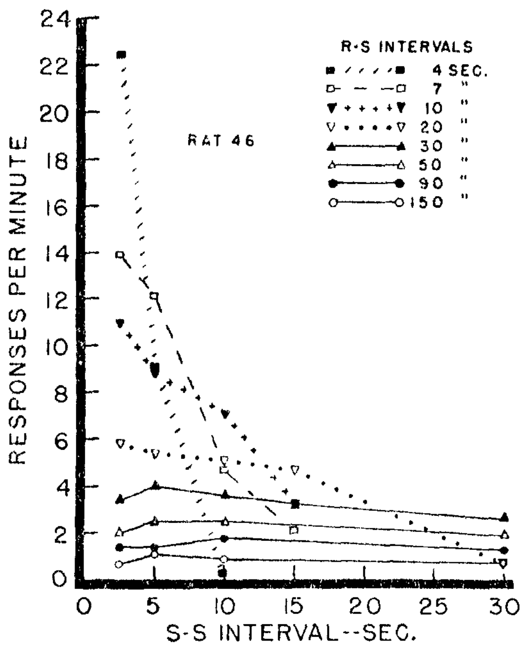

FIG. 5. Rate of avoidance responding by Rat 46, plotted against the shock-shock interval, with the response-shock interval as a parameter

Reading from bottom to top, the height on the ordinate of the four lower curves, ranging from R–S intervals of 150 to 30 sec., shows an inverse relation to the R–S interval at all points. The 20-sec. R–S-interval function maintains this relation out to the 15-sec. S–S interval, after which the curve dips sharply and crosses the lower four. With each succeeding shorter R–S interval, the curves break at a shorter S–S interval. This effect is absent from the curves for R–S intervals ranging from 30 to 150 sec. Very long S–S intervals have little or no influence on the rate of avoidance responding, which is controlled exclusively by the R–S interval. At lower values of the S–S interval, however, there does appear to be a rise in rate in the curves under consideration. It is not clear whether the rate approaches an asymptote or again drops below a maximum, since these portions of the curves are not consistent among the three animals.

DISCUSSION

The curves of Figure 1 can be interpreted in terms of interactions between two gradients, one acting to increase and one to decrease the rate of avoidance responding. The first of these functions may be termed the "distribution-of-punishment" gradient. As the R–S interval is decreased, the frequency of shocks actually received by the animals because of failure to respond in time increases, producing a rise in the probability that any nonavoidance response will be paired with shock. At shorter intervals, then, the behavior terminated by the avoidance response is more likely to be aversive and reinforcements will be more frequent, helping to account for the inverse relation between rate and the R–S intervals to the right of the maximum.

At still briefer R–S intervals, however, R_{av} itself begins to feel the effects of the shock. With a decreasing minimum interval between bar depressions and shock, R_{av} begins to receive occasional pairings with shock. The extent to which R_{av} becomes aversive depends upon the "delay-of-punishment" gradient. The decreasing rates at the left of the maxima may be interpreted as the result of the increasingly preponderant influence of the latter gradient, compared to the distribution-of-punishment gradient.

The effect of the S–S interval upon the distribution-of-punishment gradient shows up most clearly at the maximum. The shifting maximum (Fig. 3) indicates that as the S–S interval increases, the distribution-of-punishment gradient determines a smaller portion of the rate vs. R–S function, relative to the delay-of-punishment gradient. That is, at longer S–S intervals a relatively long delay of punishment of the avoidance response will suffice to decrease its rate without, however, changing the shape of the gradient. By combining these data, which reveal a direct relation between the S–S interval and the R–S

interval producing the maximum rate, with those of Figure 2, the inverse relation between the S–S interval and the maximum rate itself (Fig. 4) can be derived. With Figure 3 indicating that the delay gradient "cuts through" the distribution gradient at longer R–S intervals as the S–S interval increases, and with Figure 2 showing an inverse relation between rate and R–S interval, the maximum rate must decrease as the R–S interval containing the maximum increases.

Consideration of the delay-of-punishment gradient, determining that portion of the rate vs. R–S interval at the left of the maximum, reveals more widespread effects of the S–S interval, further supporting the analysis of the data into two separate gradients. The shift in the interval at which the curves rise from near-zero values indicates that the range of delays over which punishment completely eliminates avoidance responding increases with the S–S interval. Also, the changing rate of approach to the maximum indicates that punishment will maintain at least a partial depressive effect over a wider range of delays as the S–S interval increases.

Although short S–S intervals squeeze the delay-of-punishment gradient into a narrow range of R–S intervals, it seems unlikely that the delay gradient could be completely eliminated by further reduction of the S–S interval. This would mean that avoidance behavior could be maintained at high rates with R–S = zero seconds (shock occurring simultaneously with the response). For this reason the constant k was introduced into the equation for the distribution-of-punishment gradient. This constant sets a lower limit upon the R–S interval theoretically capable of maintaining the rate of avoidance responding. Actually, even this lower limit will not be effective, since the above equation demands an infinite rate at an interval of k seconds, a rate obviously not within the organism's capacity. At short intervals, then, there is a "capacity" variable acting with punishment to limit the minimum effective R–S interval. This variable is not represented in the equation because the number of experimental points is not adequate for evaluating the additional constant that would be required.

Further support for the proposal that both escape and avoidance behavior are strengthened by termination of a noxious event (3) is provided by the zero S–S-interval curve (Fig. 2, Rat 41), which involves both escape and avoidance. If these two types of behavior required different reinforcing mechanisms, it might be expected that the zero S–S curve would differ in some respect from the others, but it is entirely consistent.

The discontinuities noted in the curves of Figure 5 result directly from the shifting maxima in Figure 1A. For example, if the latter graph is cut vertically at R–S = 20 sec., all points will be on or to the right of the maximum except that on the lower (S–S = 30 sec.) curve, which falls to the left of the maximum. The sudden decrease in rate at the left of the maximum, reflecting the influence of the delay-of-punishment gradient, shows up as a sharp drop in the rate vs. S–S function. The displacement of this break toward lower S–S intervals mirrors the shifting maximum demonstrated in Figure 3. It is evident, then, that at lower values of the R–S parameter, the shape of the rate vs. S–S-interval function is increasingly determined by the delay-of-punishment gradient.

The reason for the absence of this effect in the curves for longer R–S intervals can be found in the relatively small number of shocks occurring at these intervals. Of these few shocks an even smaller number were not followed by R_{av}. Since there was very little difference among the longer S–S intervals with respect to the number of times the S–S interval actually occurred, it was not possible for these intervals to exert a differential effect upon the rate of avoidance responding.

It might be expected that the rise in rate at shorter S–S intervals could be accounted for by an increasing frequency of shocks, as was the distribution-of-punishment gradient. However, examination of Table 2[6] reveals no consistent relation between the S–S interval and number of shocks, with the R–S interval held constant at the values under consideration. The rise in these functions, then, must be attributed to some other factor.

One property obviously correlated with decreasing S–S intervals is the minimum interval between shocks. As this minimum interval decreases, giving a series of discrete shocks a closer resemblance to a continuous

[6] See footnote 5.

one, R_{av} begins to acquire an escape-from-shock function, since its occurrence often terminates such a series. The additional reinforcement provided by this escape function is probably responsible not only for the rise in rate with decreasing S–S intervals, but also for the maintenance of the response rate when the R–S interval is very short—for example, when S–S = R–S = 2.5 sec. As Mowrer and Ullman suggest, "Since the relief obtained by pressing the bar would be immediate and the punishment (more) remote, such behavior might be perpetuated indefinitely" (2, p. 84).

SUMMARY

The present experiment was concerned with the establishment and maintenance of a steady rate of avoidance responding and with variables determining this rate. The effects of two temporal variables were investigated with three white rats: (*a*) the shock-shock (S–S) interval, experimentally defined as the time lapse between two successive shocks if no avoidance response occurred between them, and (*b*) the response-shock (R–S) interval, or the time by which each avoidance response delayed the occurrence of shock. Each animal was run through a series of combinations of these intervals, yielding the following relations and conclusions:

1. Functions were obtained relating avoidance rate and R–S interval, with the S–S interval as a parameter. These curves passed through a maximum, the rate bearing a hyperbolic relation to the R–S interval from the maximum out to the longest interval employed. The shape of these functions was interpreted in terms of two conflicting gradients: (*a*) a delay-of-punishment gradient which operates directly upon the avoidance response to depress its rate, and (*b*) a distribution-of-punishment function which operates to depress nonavoidance behavior which would otherwise compete with the avoidance response.

2. The shape of the distribution-of-punishment gradient is independent of the S–S interval.

3. The R–S interval at which the maximum occurs in each rate vs. R–S function decreases with the S–S interval.

4. The maximum through which each rate vs. R–S function passes increases as the S–S interval decreases.

5. Both the range of delays and the maximum delay at which punishment of the avoidance response depresses its rate increase with the S–S interval.

6. Functions were obtained relating avoidance rate and S–S interval, with the R–S interval as a parameter. These curves assume a shape which depends upon interactions among several variables. As the R–S interval decreases, the functions are increasingly determined by the delay-of-punishment gradient. The effects of the latter gradient are absent from curves for the longer R–S intervals. In these curves the rate at longer intervals is determined solely by the R–S parameter.

7. The higher rates at the shorter S–S intervals and the maintenance of high rates when the R–S interval is very short were attributed to an escape-from-shock function assumed by the avoidance response at short S–S intervals.

8. Each of the three animals yielded functions which replicate those of other animals. Neither the sequences employed for presenting the intervals nor the ages of the animals appeared to be relevant variables with respect to the relations obtained.

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Received August 27, 1952.